



Top mass and properties

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For the CDF and D0 collaboration

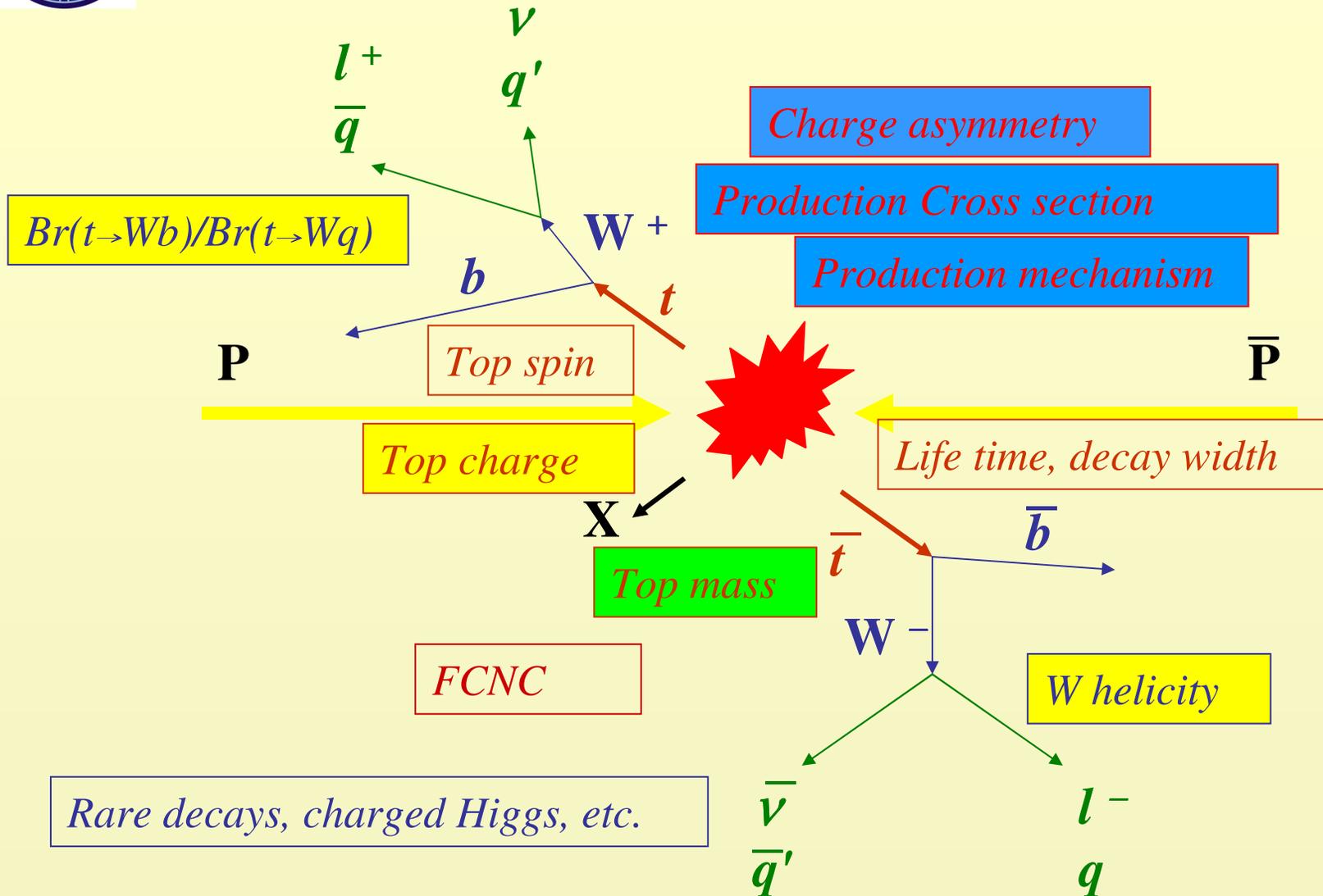


*More than ten years after Top/Truth quark
was found ...*

- *The mass is well measured.*
 - *Assuming that this is really the Top/Truth!*
- *Is it really Top/Truth of the Standard Model (SM)?*
 - *Studying the properties*

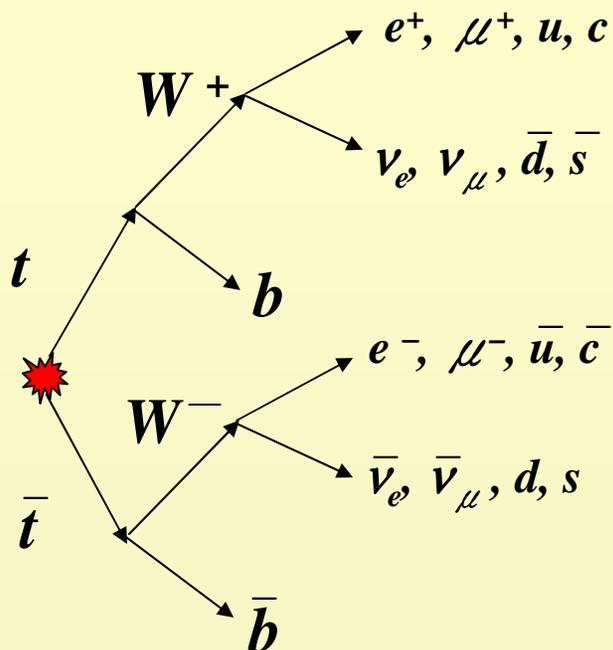


Top quark physics





Top mass measurement



- *Di-lepton (DIL) channel:*
 - both W decay to leptons.
 - in practice uses *only* e, μ .
- *Lepton+Jets (LJ) channel:*
 - one W decays to leptons.
 - the other decays to quarks.
- *Hadronic channel:*
 - both W decay to quarks.



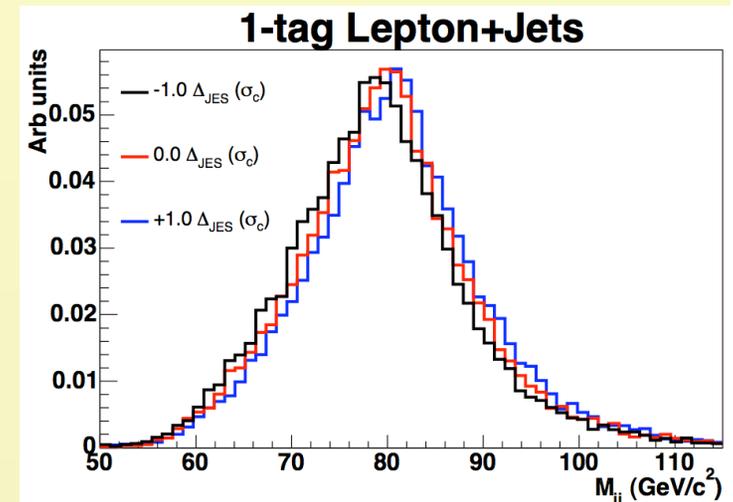
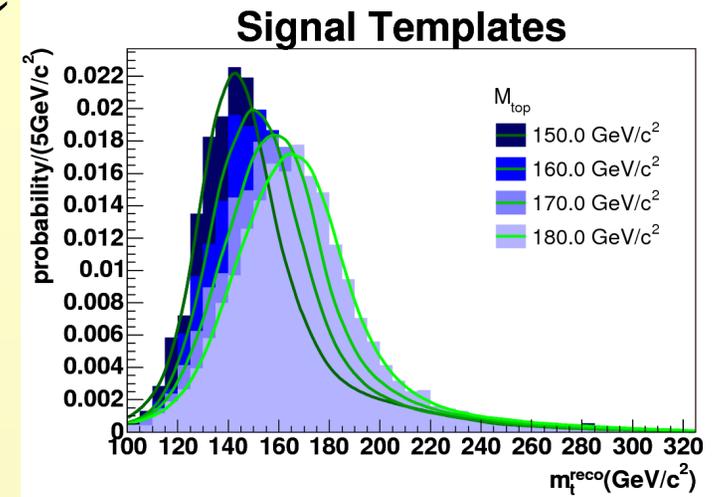
Top mass measurement

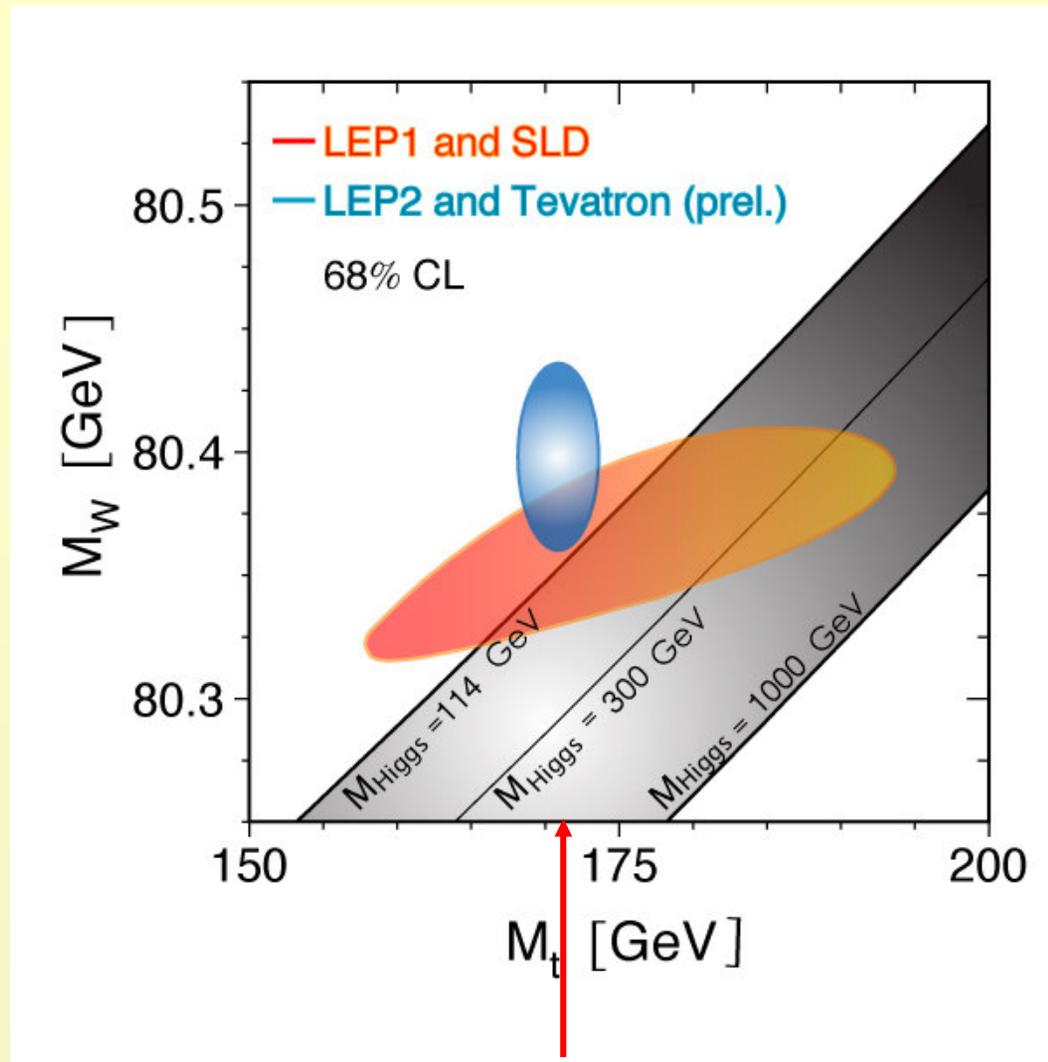


(CDF)

the techniques

- Fit to reconstructed Top mass templates
- In-situ jet energy calibration
 - Based on $W \rightarrow jj$
 - Constraint on W boson mass
- Using Matrix Element (ME):
 - Use *leading order* matrix element
 - Integrating over the phase space
 - Find the *probability density* as a function of Top mass
- Single sensitive variable, L_{xy}
- Matrix weighting
- Neutrino weighting
- Other methods not described here :
 - Kinematic method, constraint to X section, ...

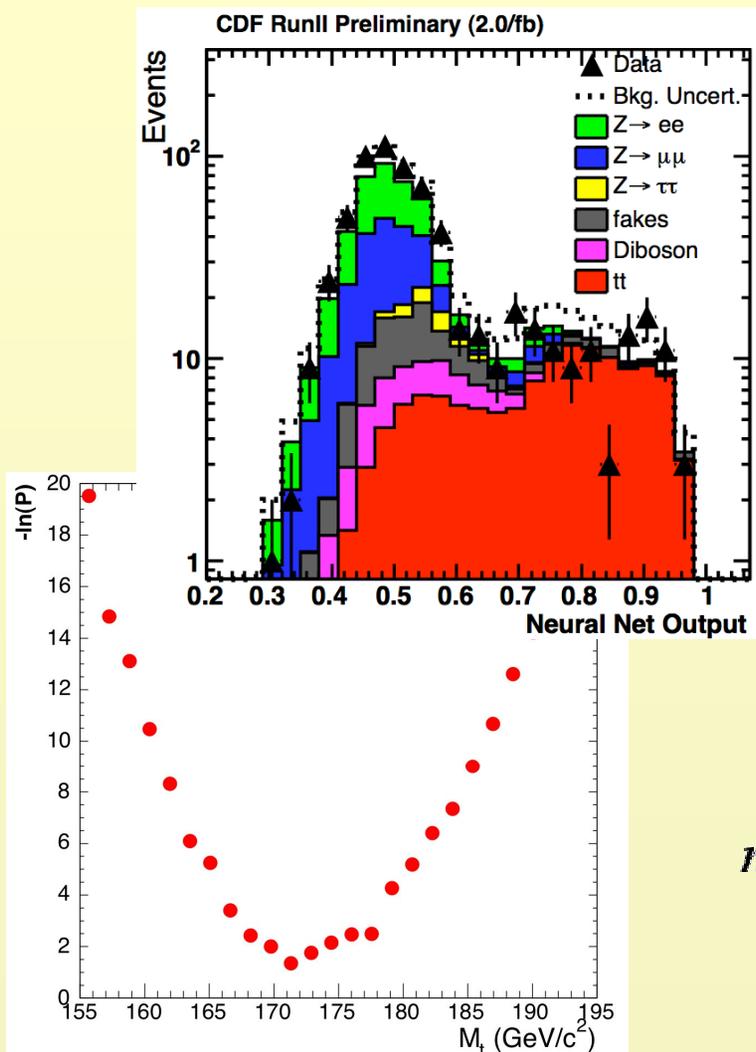




**$M_t = 170.9 \pm 1.8 \text{ GeV}/c^2$,
from 1 fb^{-1} CDF+D0 combination**



Top mass measurement, CDF

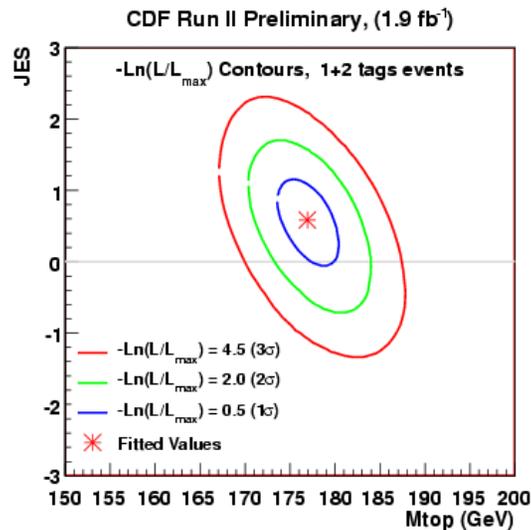


- Use *Neural Networks* to select *DIL* Top candidates then perform *ME*, 2 fb^{-1} .
 - This neural networks is *evolutional*.
 - optimized on *improving uncertainty*.

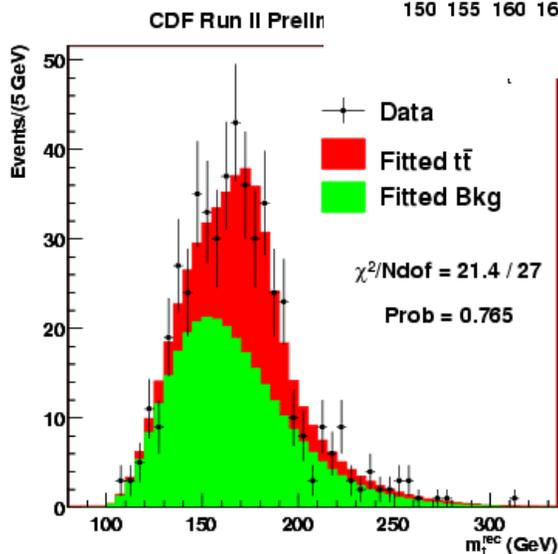
$$m_t = 171.2 \pm 2.7(\text{stat}) \pm 2.9(\text{sys}) \text{ GeV}/c^2$$



Top mass measurement, CDF



- Top mass template, *all hadronic, 1.9 fb⁻¹*
 - Use *Neural Networks* for event selection.
 - Require *b tagging*.
 - Do *In-situ jet energy calibration*.



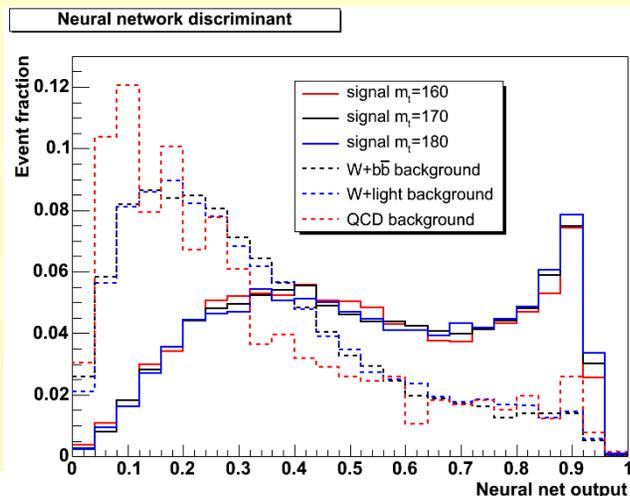
$$m_t = 177.0 \pm 3.7 \text{ (stat+JES)} \pm 1.6 \text{ (sys)} \text{ GeV}/c^2$$

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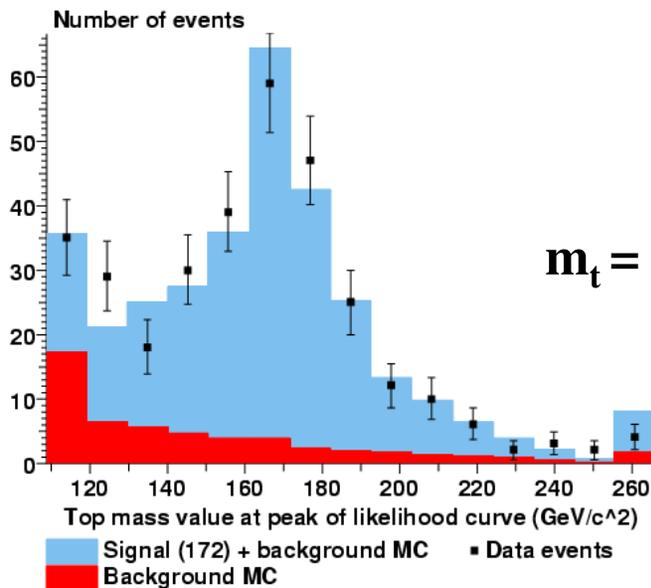
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Top mass measurement, CDF



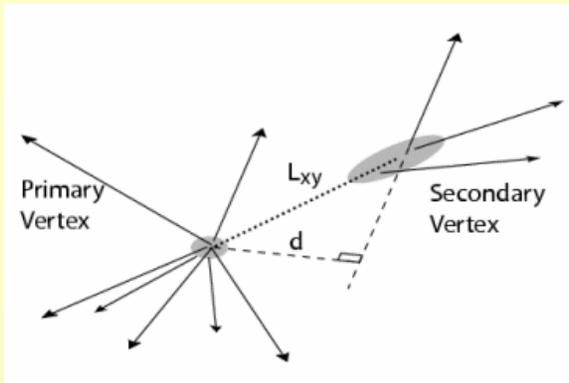
- *Matrix Element, LJ, 1.9 fb⁻¹*
 - Use *Neural Networks* for event selection
 - Require *b tagging*
 - Do *in-situ jet energy calibration*



$$m_t = 172.7 \pm 1.2 \text{ (stat)} \pm 1.3 \text{ (JES)} \pm 1.2 \text{ (sys)} \text{ GeV}/c^2$$

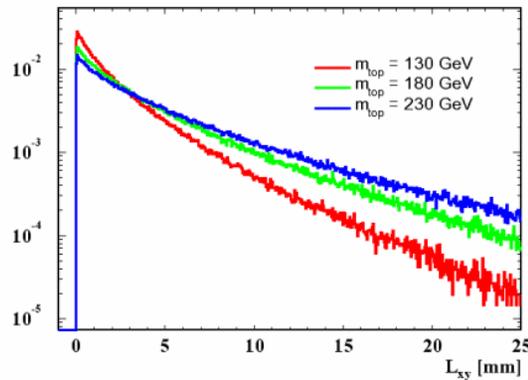


Top mass measurement, CDF

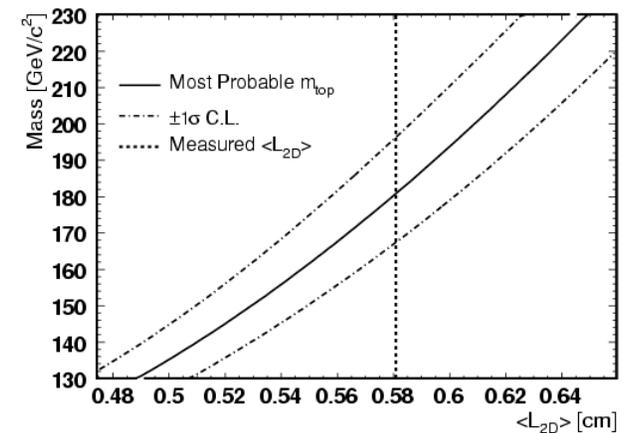
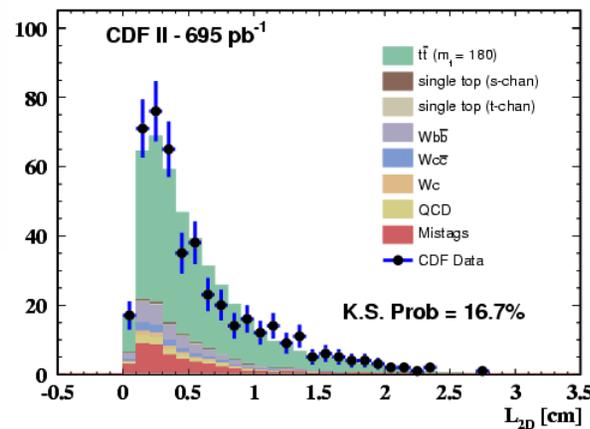


- L_{xy} , LJ , 0.7 fb^{-1}
 - L_{xy} : *Transverse decay length*
 - *Fit data to MC (sig+bkg) to find out L_{xy} .*

Transverse Decay Length

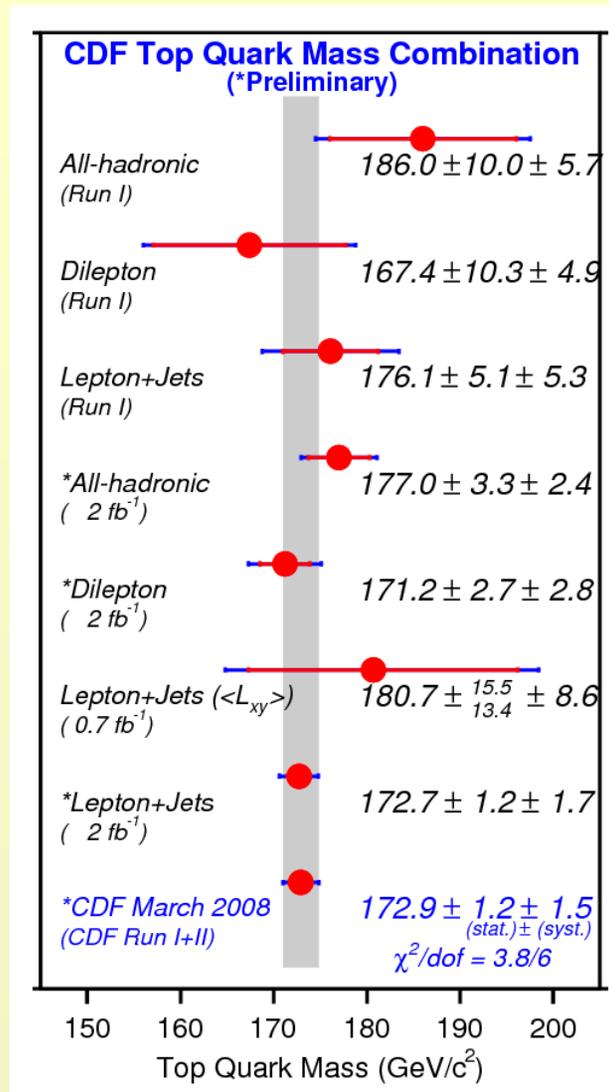


$$m_t = 180.7^{+15.5}_{-13.4} \text{ (stat)} \pm 8.6 \text{ (sys)} \text{ GeV}/c^2$$





Top mass measurement, CDF



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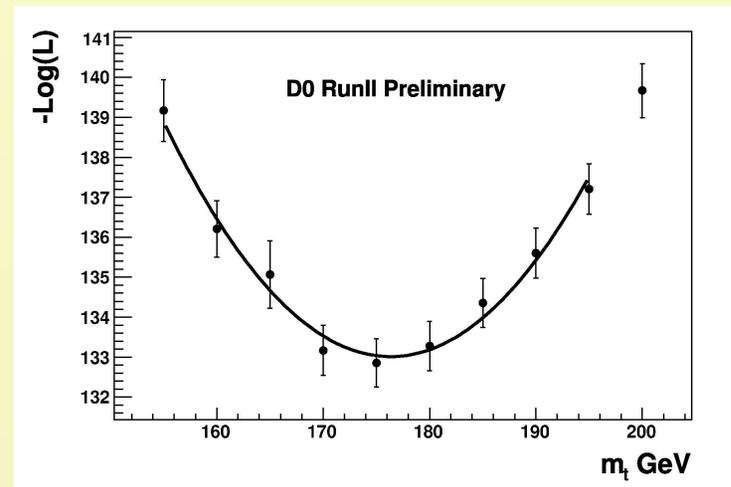
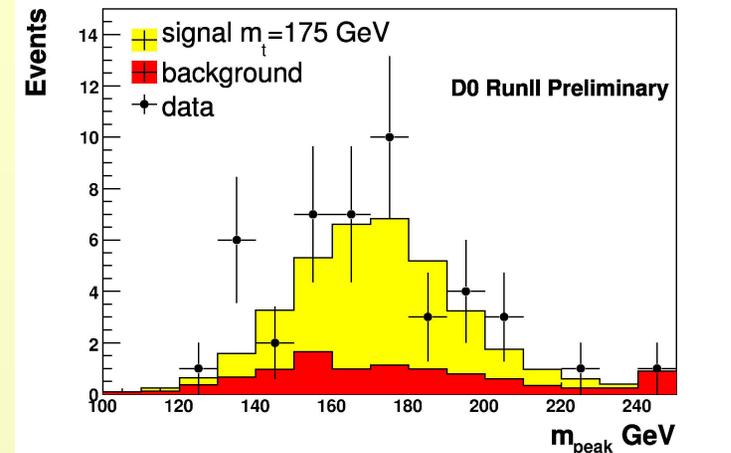
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Top mass measurement, D0

- *Matrix weighting, DIL, 1 fb^{-1}*
 - For a *given m_t* try to resolve for Top, anti-Top momenta.
 - Define *weight* for each solution.
 - Account for detector resolution.
 - Take into account the background.
 - Scan through m_t to reach the *max. weight* and the *min. of likelihood*.

$$m_t = 175.2 \pm 6.1 \text{ (stat)} \pm 3.4 \text{ (sys)} \text{ GeV}/c^2$$

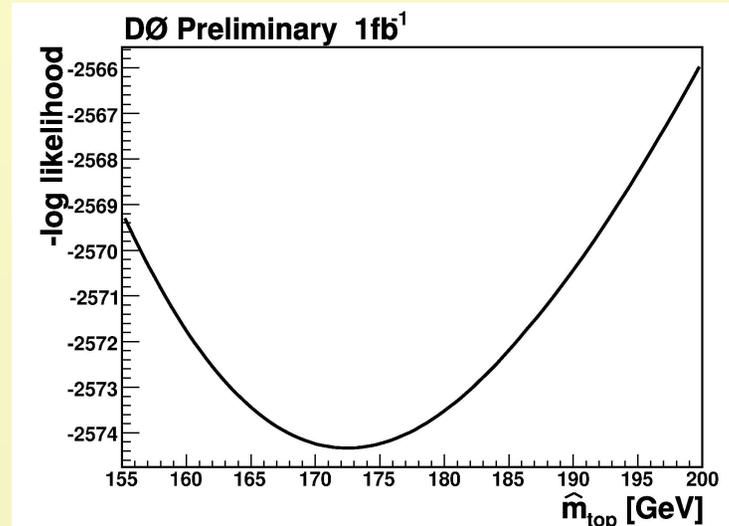
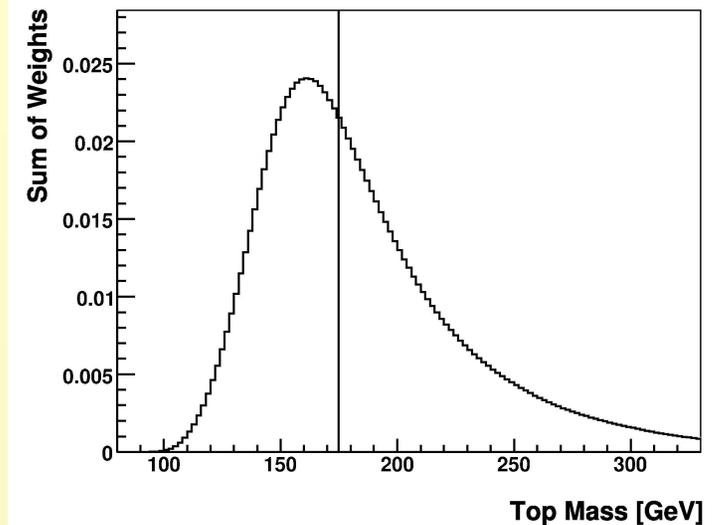




Top mass measurement, D0

- *Neutrino weighting, DIL, 1 fb⁻¹*
 - *Ignore E_t measured.*
 - *given m_t and η for each ν ; resolve for ν momenta.*
 - *For each event define **weight** based on E_t calc. and measured.*
 - *Take into account detector resolution and background.*
 - *Define likelihood.*

$$m_t = 172.5 \pm 5.8 \text{ (stat)} \pm 3.5 \text{ (sys)} \text{ GeV}/c^2$$





Top mass measurement, D0

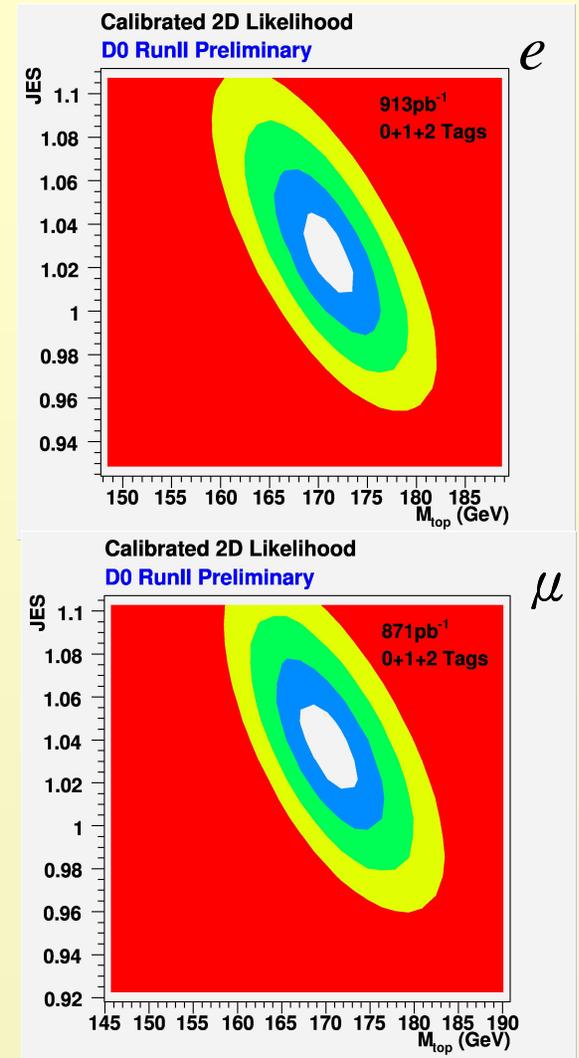


- Matrix Element, LJ , 1 fb^{-1} :
 - Use *in-situ jet energy calibration*.
 - Result *without b tagging*:

$$m_t = 170.5 \pm 2.5 \text{ (stat+JES)} \pm 1.4 \text{ (sys)} \text{ GeV}/c^2$$

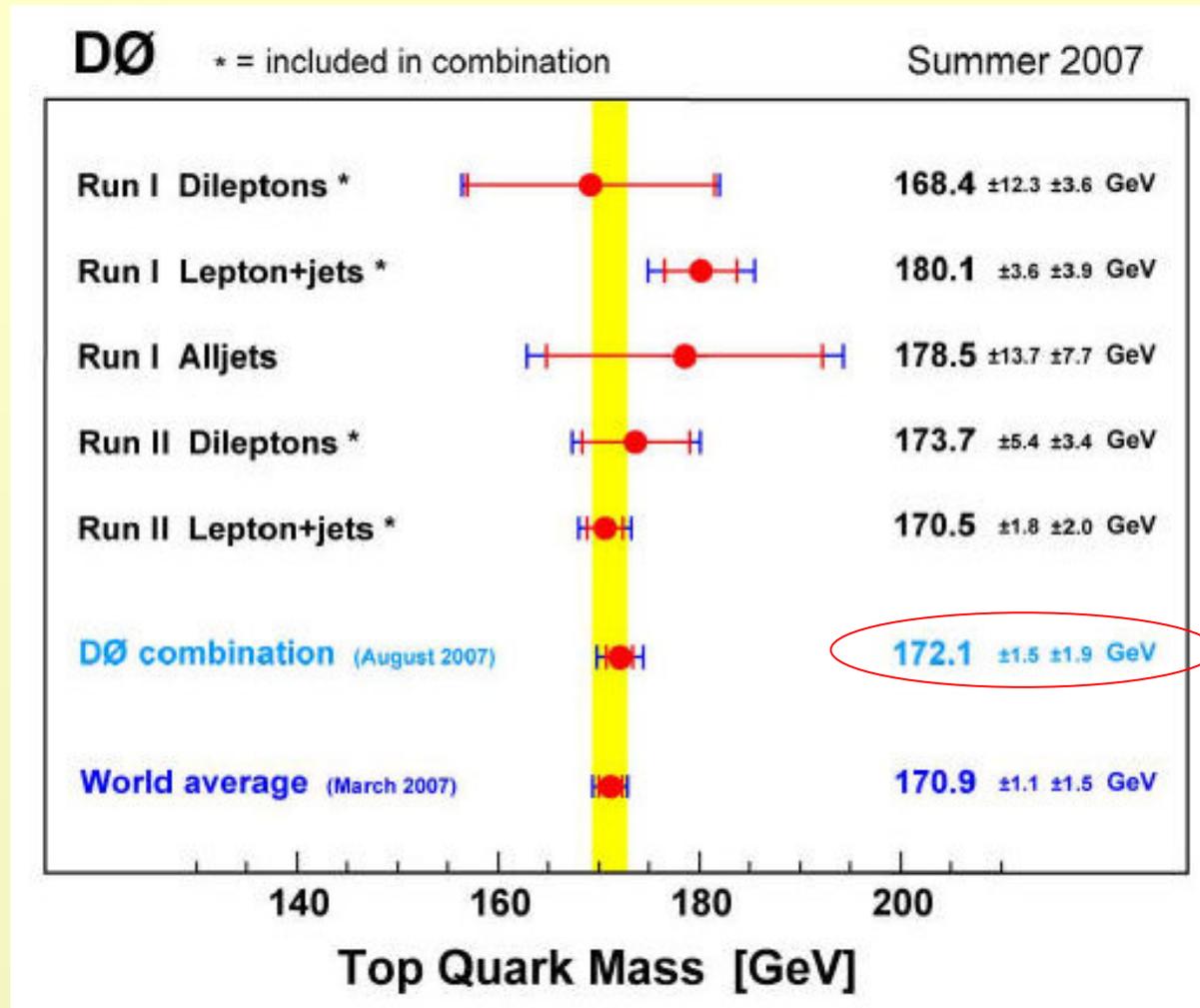
- Result *with b tagging*:

$$m_t = 170.5 \pm 2.4 \text{ (stat+JES)} \pm 1.2 \text{ (sys)} \text{ GeV}/c^2$$



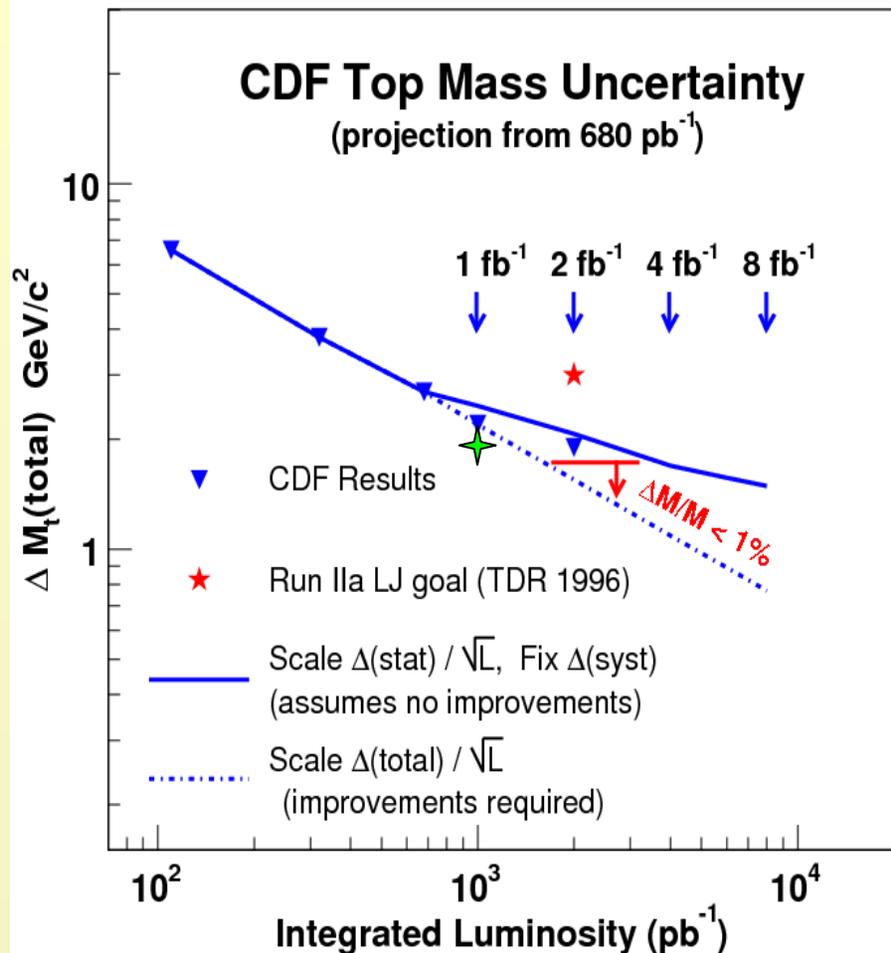


Top mass measurement, DØ





Top mass measurement, the future



★ *Tevatron Top mass, 2007 Mar.*

- *Reaching below 1% uncertainty!*
- *CDF and D0 are working together on the common systematic issues to reduce uncertainty.*



The charge of Top quark

- SM: $+2/3q$ XM: $-4/3q$
- Each event has lepton(s) and jets:
 - Pairing : Top mass as input, M_{lb}^2
 - Jet charge determination

SM : $t \rightarrow W^+ b$

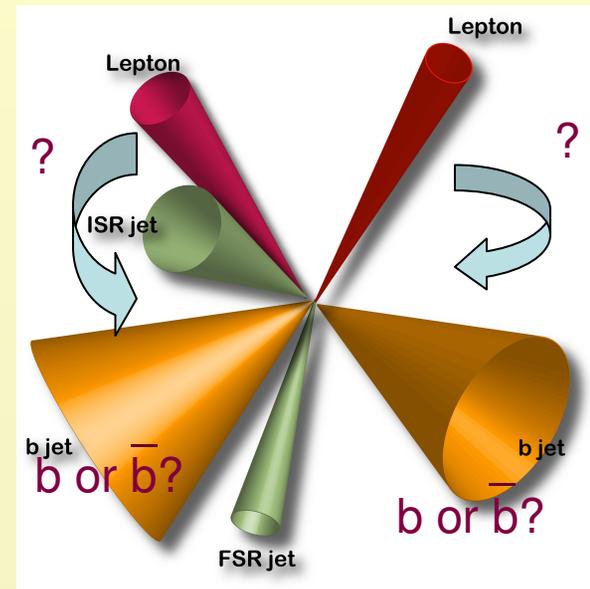
XM: $t' \rightarrow W^- b$

$$Q_{jet} = \frac{\sum |\vec{p}_i \cdot \vec{P}_{jet}|^\alpha Q_i}{\sum |\vec{p}_i \cdot \vec{P}_{jet}|^\alpha}$$

- Odds of SM vs. XM:

$$Bayes\ Factor = \frac{P(x/SM)}{P(x/XM)}$$

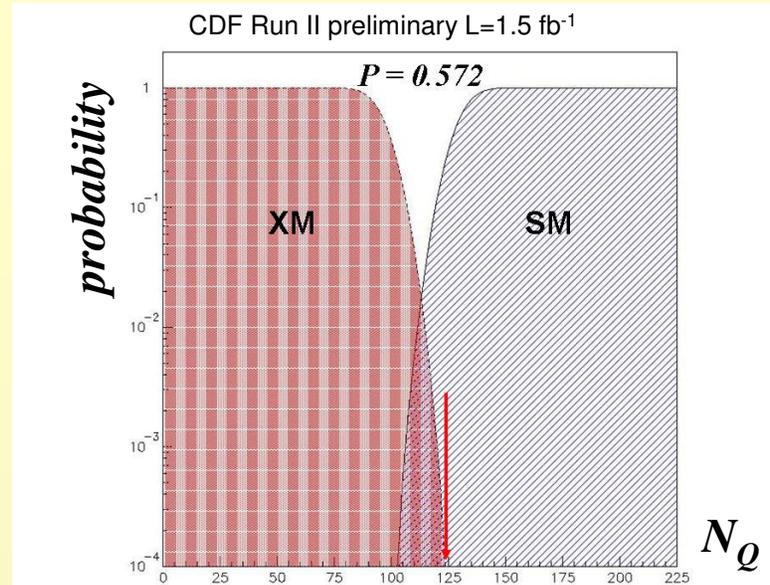
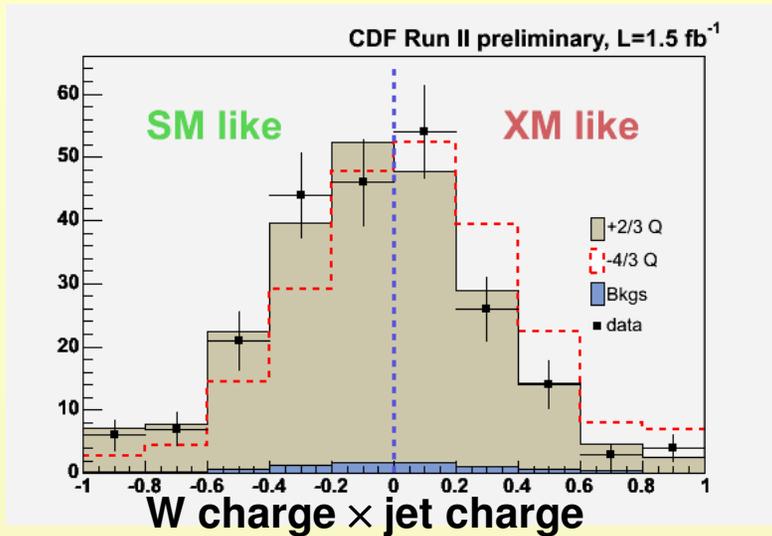
- $2 \times \text{Ln}(B.F.)$
 - 0 – 2 : Not worth than a bare mention
 - 2 – 6 : Positive
 - 6 – 10: Strong
 - > 10 : Very strong



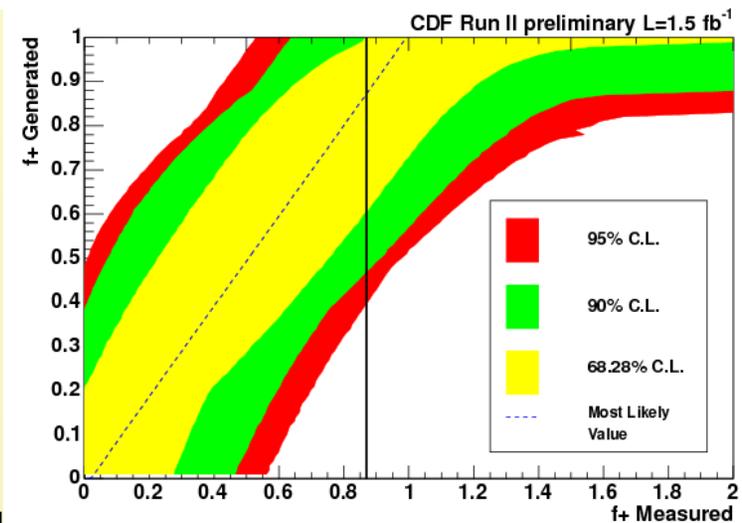


The charge of Top quark

CDF



- CDF result (1.5 fb⁻¹):
 - $2\text{Ln}(\text{Bayse factor}) = 12.0$
 - $f_+ = \text{SM like} / \text{Total}$
 $> 0.4 @ 95\% \text{ CL}$

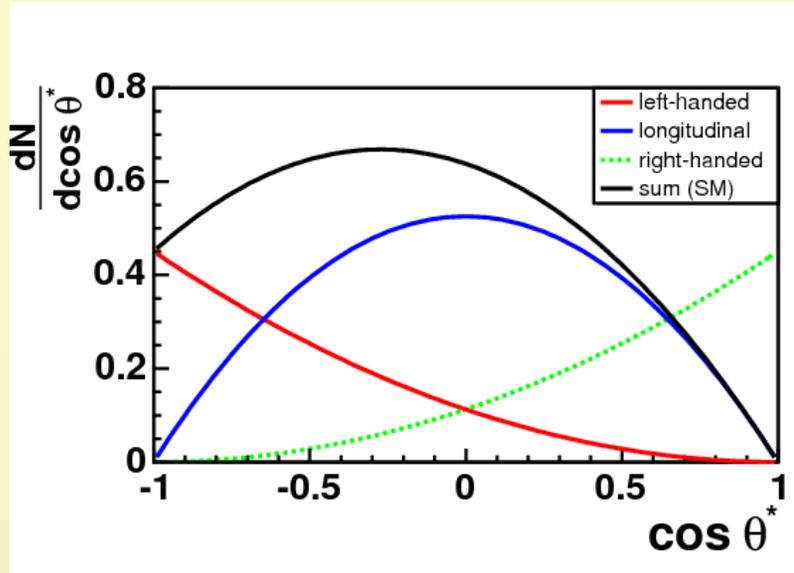
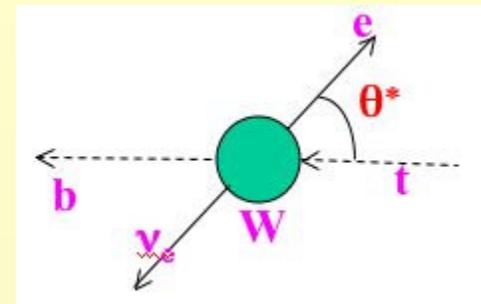
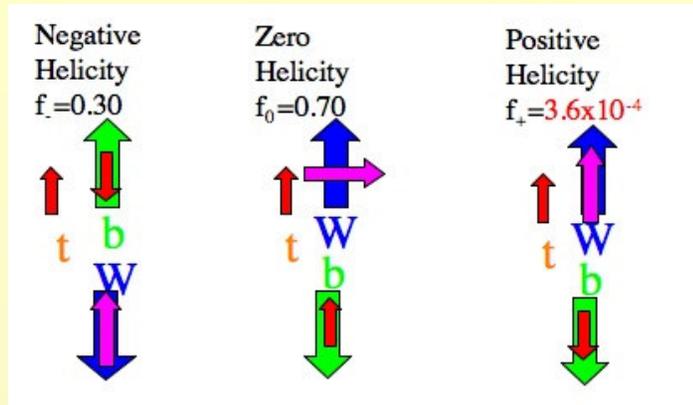


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W helicity in Top decay



Theory:

$$f_0 = 0.7, \text{ longitudinal}$$

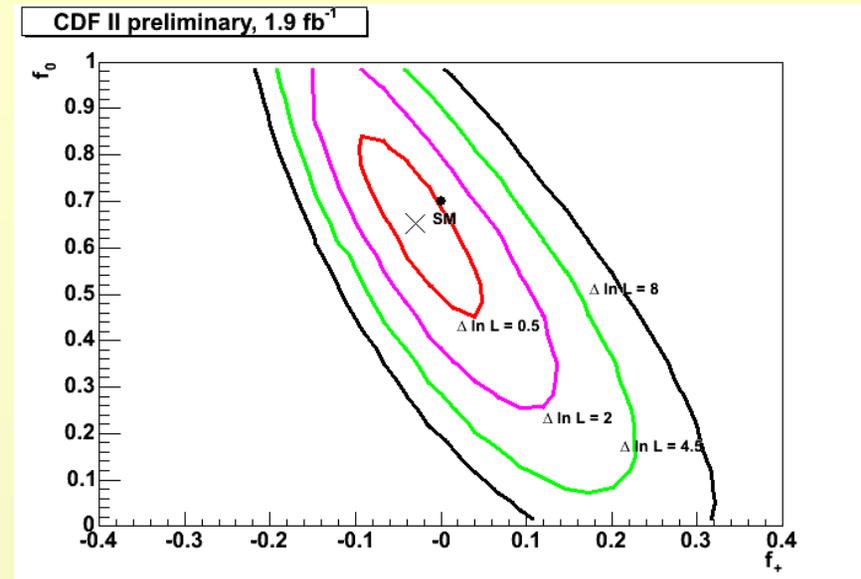
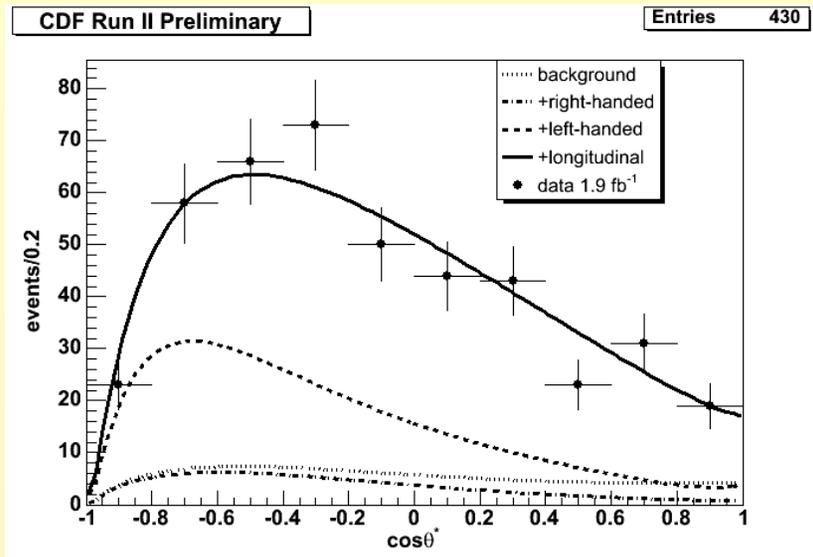
$$f_- = 0.3, \text{ left handed}$$

$$f_+ = 0, \text{ right handed}$$



W helicity in Top decay

CDF



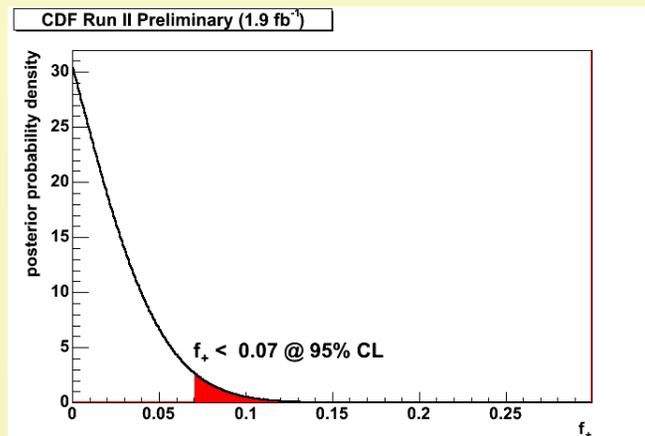
$$f_0 = 0.65 \pm 0.19 \text{ (stat)} \pm 0.03 \text{ (sys)}$$

$$f_+ = -0.03 \pm 0.07 \text{ (stat)} \pm 0.03 \text{ (sys)}$$

Fix f_0 to SM:

$$f_+ = -0.04 \pm 0.04 \text{ (stat)} \pm 0.03 \text{ (sys)}$$

$$f_+ < 0.07 \text{ @ 95\% C.L.}$$



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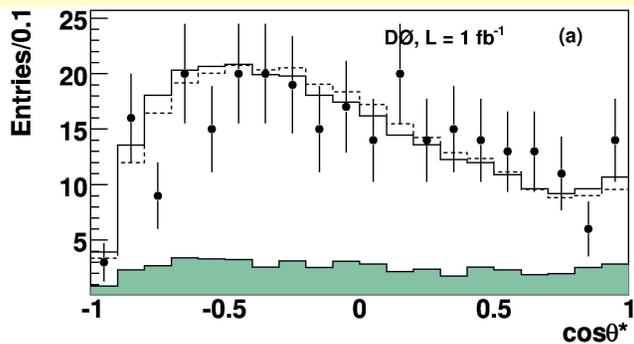


W helicity in Top decay

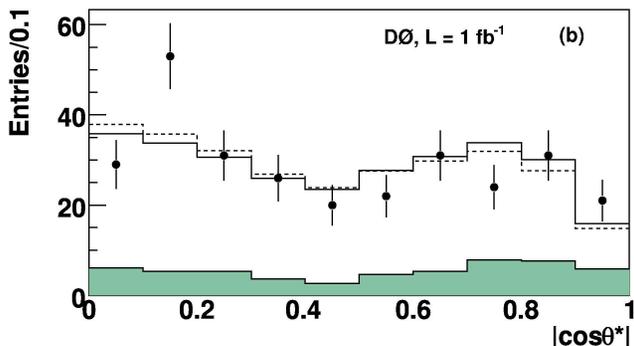


D0

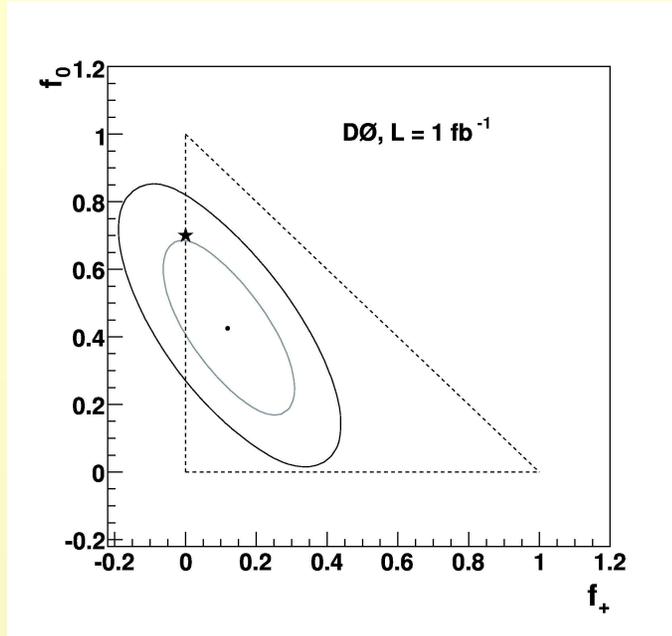
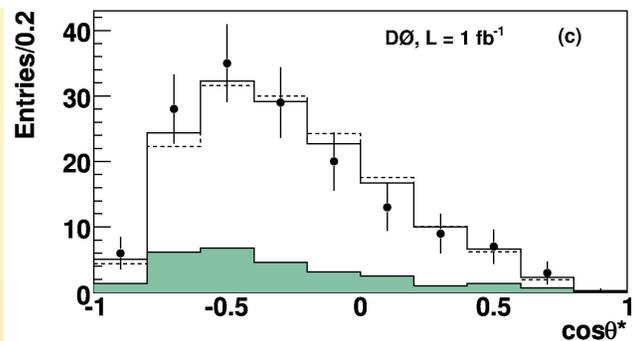
LJ, Lep.



LJ, Had.



DIL



$$f_0 = 0.425 \pm 0.166 \text{ (stat)} \pm 0.102 \text{ (sys)}$$

$$f_+ = 0.119 \pm 0.090 \text{ (stat)} \pm 0.053 \text{ (sys)}$$

Fix f_0 to SM:

$$f_+ = -0.002 \pm 0.047 \text{ (stat)} \pm 0.047 \text{ (sys)}$$

$$f_+ < 0.13 \text{ @ 95\% C.L.}$$



$$\mathcal{R} = \mathcal{B}r(t \rightarrow Wb) / \mathcal{B}r(t \rightarrow Wq)$$



D0

- *Simultaneous fit to the production cross section and \mathcal{R} .*

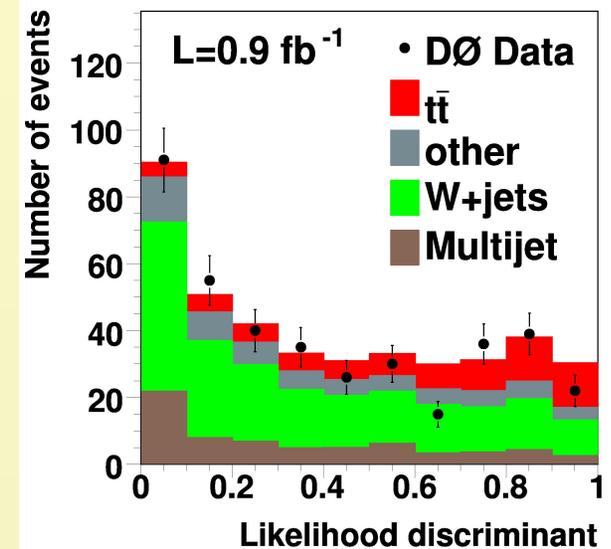
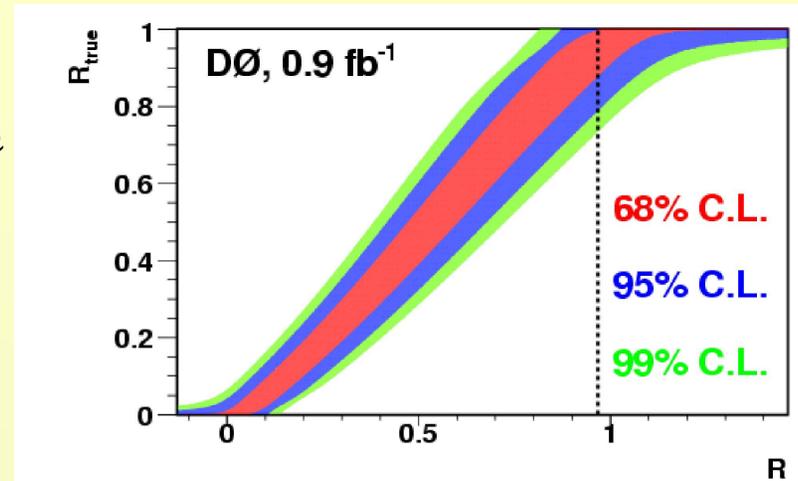
– *LJ, 0.9 fb^{-1}*

– $\mathcal{R} = 0.97^{+0.09}_{-0.08}$ (stat + sys)

> 0.79 @ 95% CL

– $|V_{tb}| > 0.89$ @ 95% CL

– $\sigma_{tt} = 8.18^{+0.90}_{-0.84}$ (stat+sys)
 ± 0.50 (lumi) pb



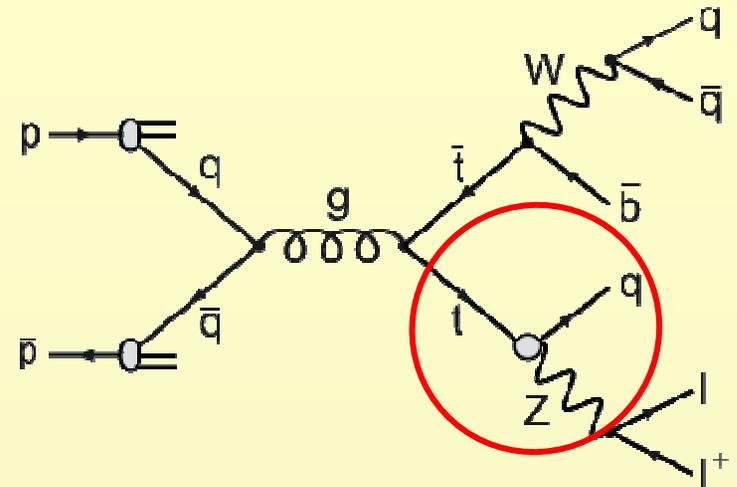


Search for FCNC in Top decay

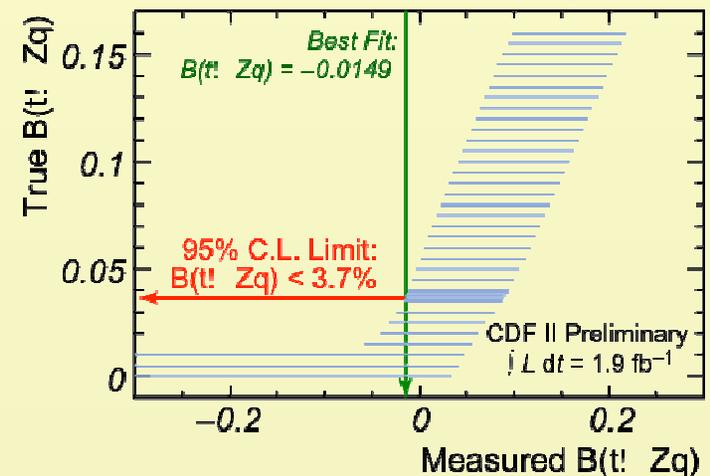


CDF

- SM : $B(t \rightarrow Zq) = O(10^{-14})$
- Beyond SM : up to $O(10^{-4})$
- At LEP : 13.7%
- Look for 2 lep. 4 jets.
- Constraint on masses of Top, Z and W.
- Best limit up to date: 3.7%



FCNC Feldman-Cousins Band (95% C.L.)





Conclusion

- *More than ten years after the Top quark discovery:*
 - *Top quark mass is well measured to 1.1% level!*
 - *Up to date, within uncertainties, all measured quantities are consistent with the Standard Model expectations.*
 - *Top charge, W helicity, R_b , FCNC*
 - *Analysis in progress or not reported here.*
 - *Life time, decay width, top spin correlation, charged Higgs search, etc.*
 - *This is just the beginning of the sensitive studies of the Top quark properties! There are much room ahead for surprises!*